

Tracking Operations During the Mariner 10 Mercury Encounter

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Tracking operations during the Mariner 10 Mercury encounter were quite smooth and highly successful. Contributing factors included a lack of any substantial Mercurian atmosphere and, hence, signal refraction, relatively small gravitational perturbation of the spacecraft by Mercury, and a great deal more experience with the Block IV S- and X-band receivers and the digitally controlled oscillators. This report describes the pre-encounter planning and subsequent analysis of tracking operations during the Mariner 10 Mercury encounter phase.

I. Introduction

On March 29, 1974, at 20:46:31.9 GMT (spacecraft time), the Mariner 10 spacecraft reached closest approach to the planet Mercury. This encounter was simultaneously visible to both the Goldstone and the Australian complexes, thus allowing prime participation by two 64-meter Deep Space Stations (DSSs)—DSS 14 and DSS 43. A successful Mercury encounter was the foremost goal of the Mariner Venus/Mercury mission, and was the focal point of intense interest since it would be the first “close-up” examination of the heretofore little-known planet Mercury. Significant configuration at the DSS during Mercury encounter included the Block IV S- and X-band receivers at DSS 14 and the digitally controlled oscillators (DCOs) and open-loop receivers at both DSS 14 and DSS 43. A combination of circumstances resulted in this encounter being relatively uncomplicated from a tracking operations standpoint, these being:

- (1) Mercury has essentially no atmosphere, thereby greatly reducing the signal refraction and the corresponding uncertainties in the doppler at, and times of, enter and exit occultation.
- (2) The mass of Mercury is relatively small, thereby inducing only a small perturbation in the near-encounter doppler.
- (3) Although the Block IV receivers and the DCOs were relatively new, considerable operational experience with them had been obtained in the previous 4-6 months, and especially during the critical Jupiter and Venus encounter phases (see Refs. 1 and 2).

The above augured well for generally successful tracking operations during the Mercury encounter, and, indeed, this was the case.

II. Uplink Tuning Strategy

The initial uplink strategy chosen by the Radio Science/Occultation Team was to have the spacecraft in the two-way mode at both enter and exit occultations. More specifically, it was hoped that acquisition of the uplink at exit occultation could be effected within 2 seconds of the actual spacecraft emergence. The only possible way to accomplish this goal would be to hit the spacecraft receiver with (very close to) the receiver best lock frequency (which with doppler accounted for = XA) at the time of emergence. Factored into the probability of success of this attempt were the uncertainties in doppler at, and time of, emergence and uncertainty in the spacecraft nominal (no doppler) best lock frequency. Additional spacecraft receiver data received and analyzed by the Radio Science/Occultation Team at approximately encounter minus 24 hours indicated substantial possibility that the uplink acquisition plan at emergence would not succeed, and therefore an uplink acquisition "insurance" sweep, which had been proposed some weeks earlier by the DSN Network Operations Analysis Group, was adopted and scheduled at approximately exit occultation plus 7 minutes. The final uplink tuning strategy, seen in Fig. 1, was as follows:

- (1) Spacecraft to enter occultation in the two-way mode with ground transmitted frequency (TSF) to be equal to predicted XA at enter occultation.
- (2) During occultation, ground transmitter to be snapped to a TSF equal to predicted XA of exit occultation.
- (3) Approximately 7 minutes after exit occultation, the ground transmitter to be swept approximately ± 45 Hz (at VCO level) about predicted XA.

The effects of uplink tuning as seen in the downlink two-way doppler are presented in Fig. 2. The values used for enter and exit transmitted frequency (= predicted XA) were, respectively:

$$(X_A)_P)_{EN} = 22.0161180 \text{ MHz}$$

$$(X_A)_P)_{EX} = 22.0160820 \text{ MHz}$$

Analysis of Probe Ephemeris Tape (PET) N802 ("best" post-encounter PET) shows the actual XAs to be:

$$(X_A)_A)_{EN} = 22.0161197 \text{ MHz}$$

$$(X_A)_A)_{EX} = 22.0160813 \text{ MHz}$$

yielding a difference between transmitted and actual (trajectory difference only) of:

$$\Delta X_A)_{EN} = (X_A)_A - (X_A)_P)_{EN} = +1.7 \text{ Hz}$$

$$\Delta X_A)_{EX} = (X_A)_A - (X_A)_P)_{EX} = -0.7 \text{ Hz}$$

Based on the above (trajectory) differences, one would expect that the attempt to acquire the uplink quickly and without tuning would have a high probability of success. The best trajectory estimates of the occultation times (PET N802) were:

$$\text{Enter occultation} = 20:56:12 \text{ GMT}$$

$$\text{Exit occultation} = 21:07:33 \text{ GMT}$$

Substantiating the above are the event times as recorded by the open-loop receivers (and supplied by Dr. A. Kliore, Section 391):

$$\text{Enter occultation} = 20:56:11.69 \text{ GMT}$$

$$\text{Exit occultation} = 21:07:33.03 \text{ GMT}$$

$$\text{One-way/two-way transition} = 21:07:43.55 \text{ GMT}$$

It is therefore concluded that the uplink was acquired approximately $10\frac{1}{2}$ seconds after emergence of the spacecraft. Although this acquisition time exceeded the goal of a 2-second acquisition considerably, it very adequately fulfilled the broader goal of locking the uplink quickly and without tuning.

III. Accuracy of Pre-encounter Orbit Determination Solutions as Regards Tracking Operations Planning

Because of the planned attempt to acquire the uplink at exit occultation without tuning, it was particularly desirable to know the enter and exit occultation XAs to the highest degree possible. Figures 3 and 4, respectively, show the enter and exit occultation XAs versus time. The various PETs shown were received over the last several weeks prior to encounter and in the following chronological order:

PET Number C180

C496

C617

C618 {actually used for the encounter}

N802 {"best" post-encounter solution}

In Ref. 2, it was suggested that the practice of holding off the selection of final critical phase tracking operations parameters (event times and frequencies) until a final orbit determination solution is received in the last hours before an encounter is unwarranted and risks operational errors due to hasty implementation. Similarly these data substantiate that conclusion as there is no clear-cut progression in accuracy (to the actual) among the PETs received.

IV. Ground Receiver Operations at Exit Occultation

As in the two previous critical phase encounters (Pioneer 10-Jupiter and Mariner Venus/Mercury-Venus; see Refs. 1 and 2), it was decided that the DCOs would be used in the ACQUISITION MODE (ACQ MODE). The sweep rate selected was ± 1000 hertz/second (S-band), in combination with the following:

Tracking loop bandwidth	= 152 Hz (Block III)
	100 Hz (Block IV)
Sweep range	= ± 2000 Hz (DSS 14, S-band)
	± 3000 Hz (DSS 43, S-band)

At both stations the Block III backup receiver was swept for one-way, while all other receivers were swept for two-way (DSS 14) or three-way (DSS 43). During the approximately 10½ seconds of one-way data following exit occultation and prior to uplink acquisition, neither backup Block III receiver locked (note that these data were recorded on the open-loop receivers). However, both prime S-band receivers at DSS 14 and DSS 43 locked to the two-way (DSS 14) or three-way (DSS 43) downlink at the very first time possible. Figures 5 and 6 show the exit occultation acquisitions for DSS 14 and DSS 43, respectively. As can be seen in each case, ground receiver lock was achieved at the very first zero (predicted doppler) crossing after the two-way/three-way downlink signal appearance (21:07:43.55 GMT). One interesting point of note is that the receiver VCO stays shorted continuously during the ACQ MODE on the Block IV receiver, but drifts during the ACQ MODE on the Block III receiver; this is clearly seen in Fig. 5

(Block IV) versus that seen in Fig. 6 (Block III). The linear drift seen in Fig. 5 is that due to doppler.

V. Summary of Key Spacecraft and Ground Events at the DSS During the Mercury Encounter Phase

Table 1 provides a summary of important spacecraft and DSS events (all in ground received time) during the Mercury encounter occultation phase.

VI. Summary of Tracking Operations During the Mercury Encounter Phase

Tracking operations during Mercury encounter were extremely smooth and resulted in a highly successful encounter. Factors which simplified and contributed to the success of tracking operations were:

- (1) Lack of any substantial Mercurian atmosphere.
- (2) Small gravitational effect of Mercury on the spacecraft.
- (3) Far greater experience with the DCOs and Block IV S- and X-band receiver operations than in the previous planetary encounters.

The most difficult operation was the attempt to acquire the uplink almost immediately upon exit with no tuning, and, although the most optimally desired goal of a 2-second or less acquisition was not met, the broader goal of a very rapid acquisition of the uplink with no tuning was very soundly fulfilled.

References

1. Berman, A. L., "Tracking Operations During the Pioneer 10 Encounter," in *The Deep Space Network Progress Report 42-20*, pp. 190-195, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1974.
2. Berman, A. L., and Spradlin, G. L., "Tracking Operations During the Mariner 10 Venus Encounter," in *The Deep Space Network Progress Report 42-21*, pp. 95-107, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1974.

Table 1. Spacecraft and DSS events during Mercury encounter occultation phase

Event	Ground received time (Mar. 29, 1974), GMT
Enter occultation	20:56:11.69
DSS 43 drop lock	20:56:12
DSS 14 S-band Block IV drop lock	20:56:12
DSS 14 X-band Block IV drop lock	20:56:12
Exit occultation one-way	21:07:33.03
Downlink one-way to two-way	21:07:43.55
DSS 43 acquire downlink	21:07:46
DSS 14 S-band Block IV acquire downlink	21:07:46
DSS 14 X-band Block IV acquire downlink	21:09:56

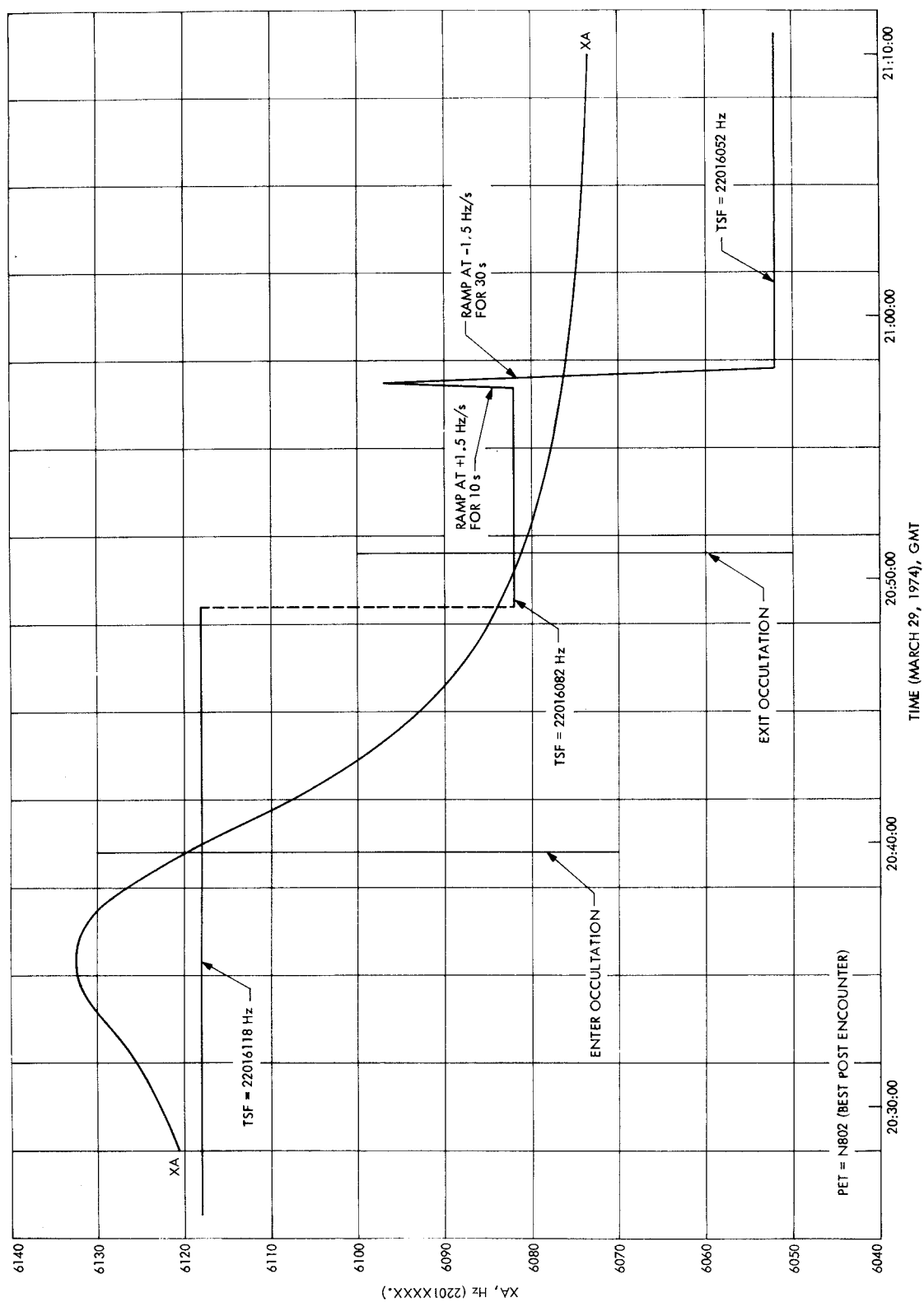


Fig. 1. XA and exciter tuning pattern for Mercury encounter (DSS 14)

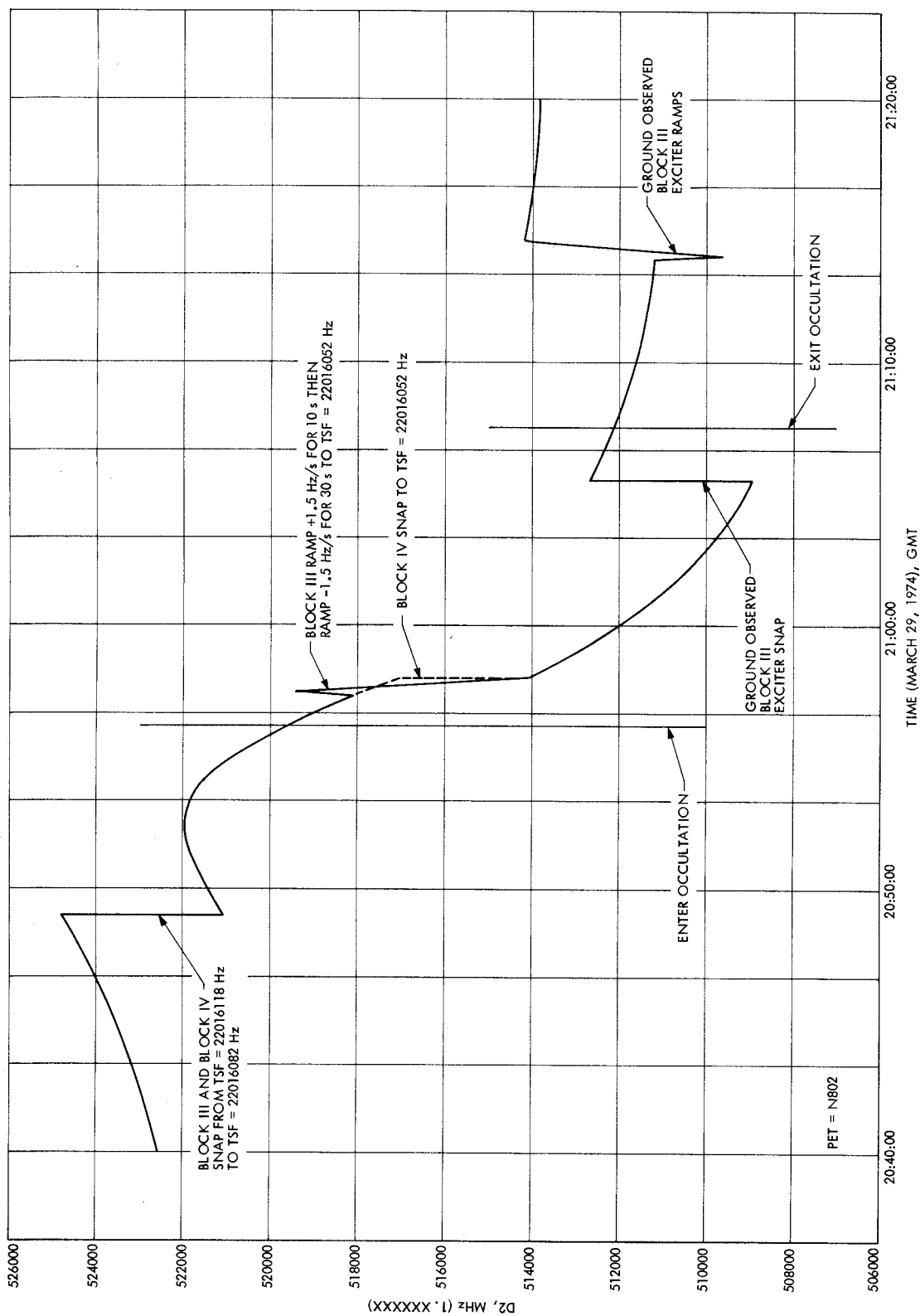


Fig. 2. S-band D2 at Mercury encounter (DSS 14)

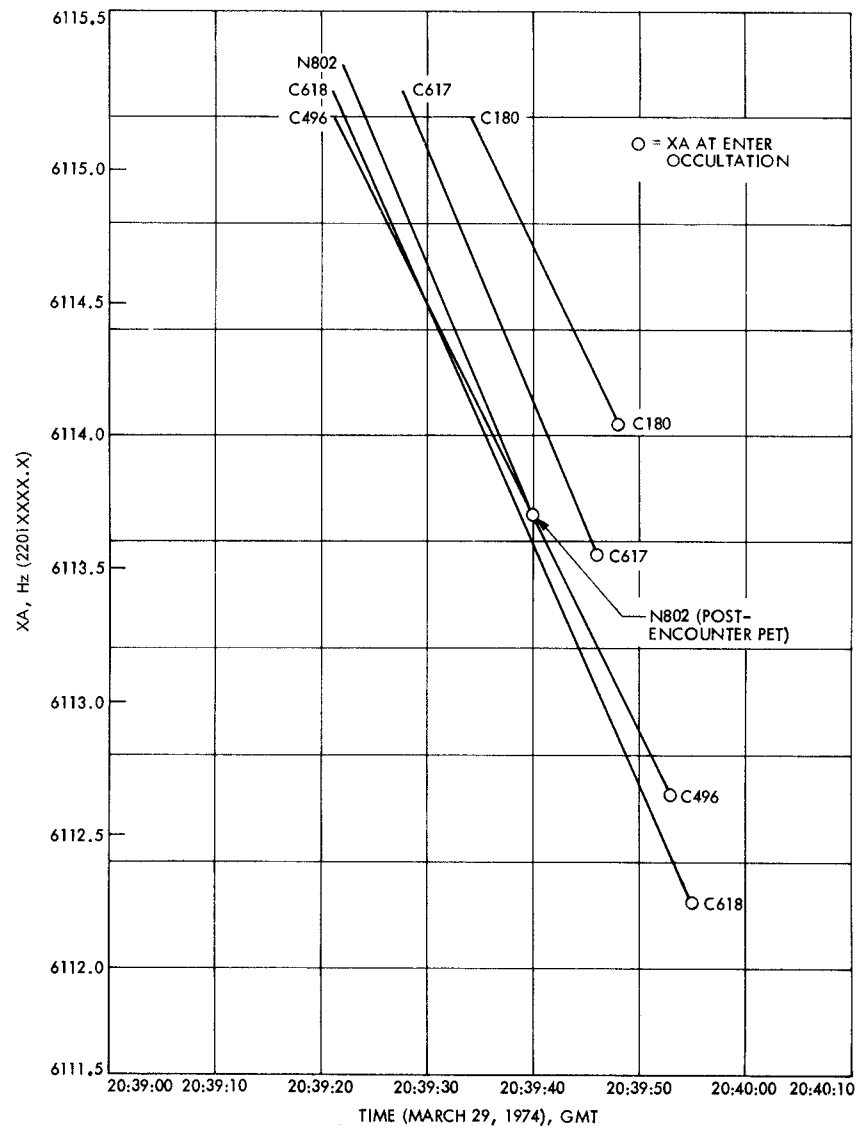


Fig. 3. Enter occultation XA for pre-Mercury encounter orbital solutions

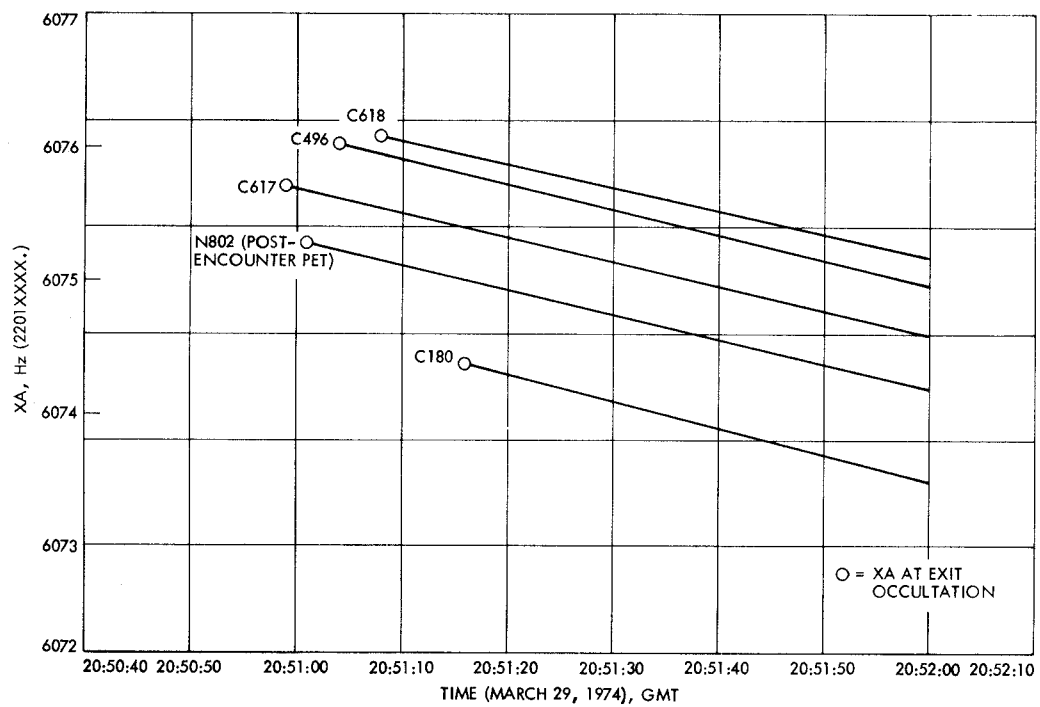


Fig. 4. Exit occultation XA for pre-Mercury encounter orbital solutions

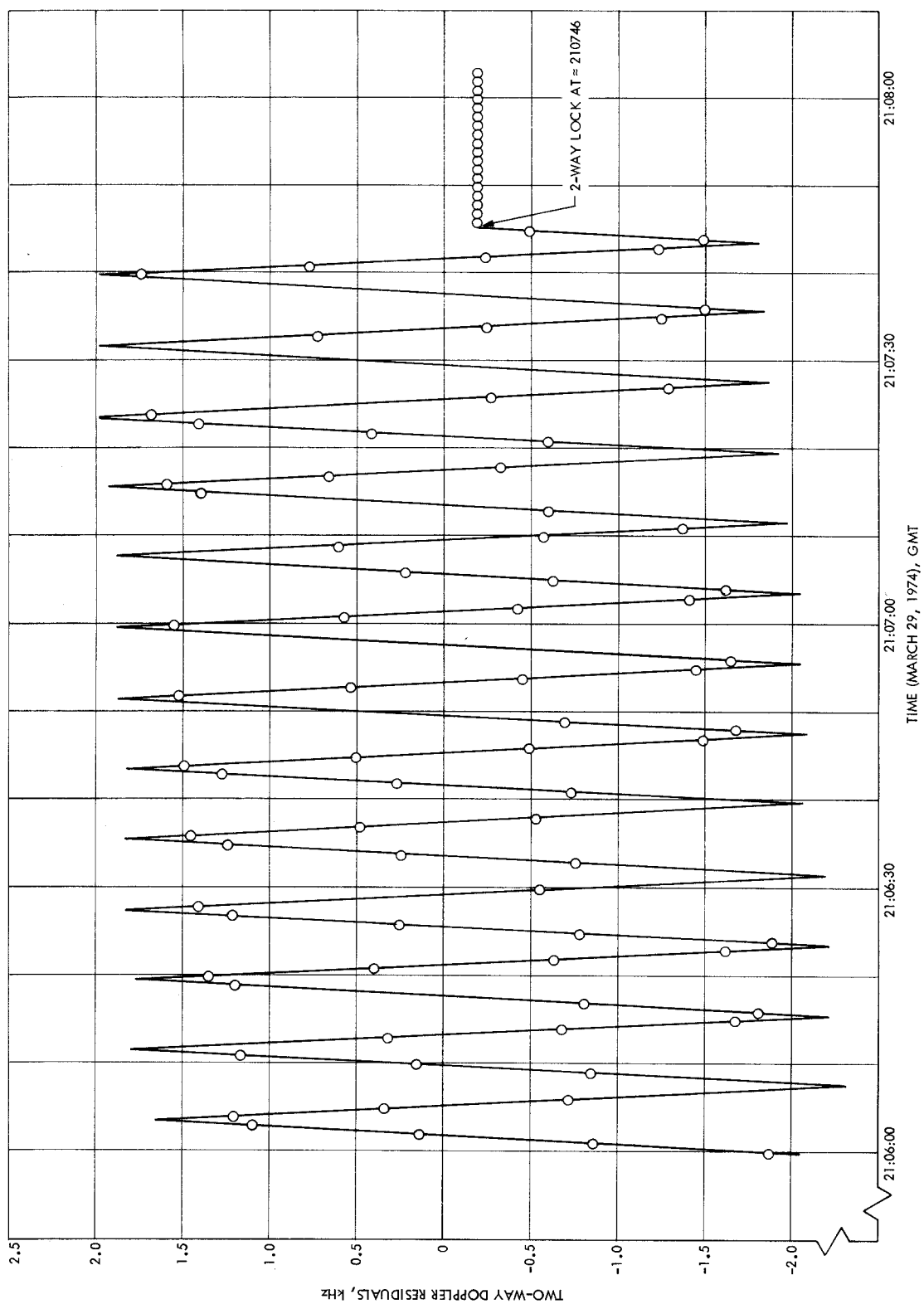


Fig. 5. Acquisition tuning pattern for Mercury exit occultation (DSS 14 Block IV S-band receiver)

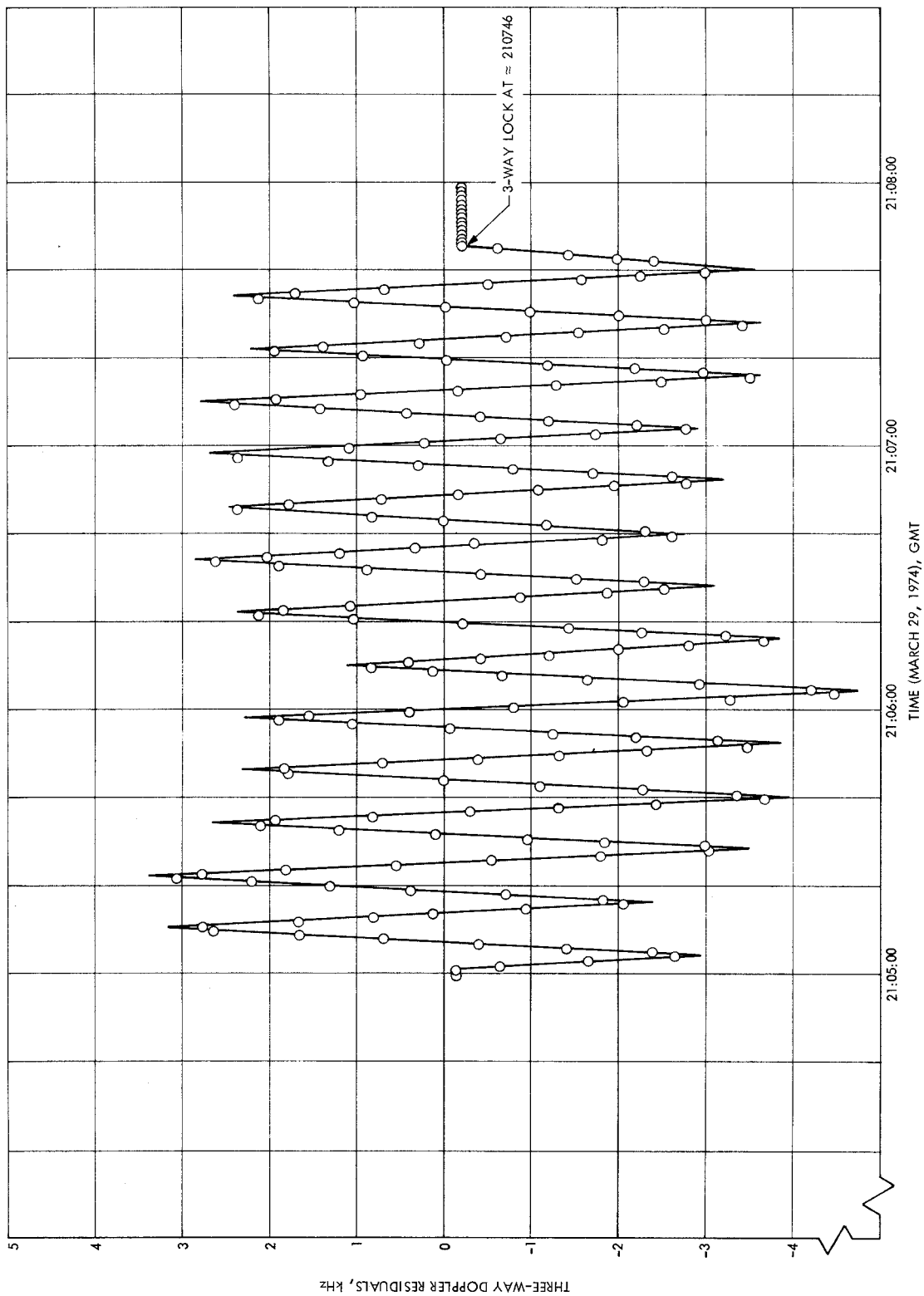


Fig. 6. Acquisition tuning pattern for Mercury exit occultation (DSS 43)